REAL-TIME VISUAL SERVO CONTROL OF TWO-LINK AND THREE DOF ROBOT MANIPULATOR

A Thesis submitted in partial fulfilment of the Requirements for the degree of

Bachelor of Technology and
Master of Technology Dual Degree

In

Electrical Engineering

By
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Rourkela, Odisha, 769008, India

June 2016

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Under the guidance of

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Dedicated to…

My Parents and my well wishers

DEPARTMENT OF ELECTRICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ROURKELA – 769008, ODISHA, INDIA

Certificate

This is to certify that the work done in thesis "Real-Time Visual Servo Control of Two Link and Three DOF Robot Manipulator" by Shobhit Sharma (711EE2130) in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology and Master of Technology Dual Degree in Electrical Engineering during session 2011-2016 in the Department of Electrical Engineering, National Institute of Technology Rourkela is an authentic work carried out by her under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Place: NIT Rourkela

Date: 31th May2016

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ROURKELA – 769008, ODISHA, INDIA

Declaration

I, Shobhit Sharma, declare that this thesis titled, "**Real-Time Visual Servo Control of Two Link and Three DOF Robot Manipulator**" and the work presented in it are my own.

I confirm that:

- I certify that the work contained in this thesis is original and has been done by me under the guidance of my supervisor.
- The work has not been submitted to any other Institute for any degree or diploma.
- I have followed the guidelines provided by the Institute in preparing the thesis.
- I have confirmed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.
- Whenever I have used materials (data, theoretical analysis, figures, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

Shobhit Sharma
31th May 2016

Acknowledgement

I want to genuinely express my deep sense of thanks to my supervisor Prof. Dipti Patra, for her immense support and highly coherent guidance. Her motivation and encouragement has helped me to go through my master’s with productive results. Her deep and diverse knowledge has culminated the thirst to pursue for knowledge. She has taught me how to be good researcher at the same time being the most polite and patient person. I express everlasting gratitude for all the time and interest she has invested on me. I sincerely thank her for bringing back the pursuit for knowledge. I want to thank Department of Electrical Engineering, NIT Rourkela for providing us the opportunity to learn and experience them.

This journey wouldn’t have been filled with fun without my senior Ph.D. Mr. Umesh Kumar, Miss Sritama Roy and Simulation lab Assistant Rama Prasad Samantaray. These five years had been the most memorable time of my life owing to my ever loving friends. Completion of my degree wouldn’t have been possible without my parents, with everlasting support and love. Lastly I express my love for my best buddie the almighty who has remained with me in every hurdle I have faced.

NIT Rourkela

May 31, 2016

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Abstract

This project presents experimental results of position-based visual servoing control process of a 3R robot using 2 fixed cameras. Visual servoing concerns several field of research including vision systems, robotics and automatic control. This method deal with real time changes in the relative position of the target-object with respect to robot. It is have good accuracy with independency of Manipulator servo control structure from the target pose coordinates are the additional advantages of this method. The applications of visually guided systems are many: from intelligent homes to automotive industry. Visual servoing are also useful for a wide range of applications and it can be used to control many different systems (manipulator arms, mobile robots, aircraft, etc.). Visual servoing systems are generally divide depends on the number of camera, on the position of the camera with respect to the robot, on the design of the error function to robot.

This project presents an approach for visual robot control. Existing approaches are increased in such a way that depth and position information of block or object is estimate during the motion of the robot. That is done by the visual tracking of an object throughout the trajectory. Vision designed robotics has been a major research area for more time. However, one of the open and commonly problems in the area is the requirement for exchange of the experiences and ideas. We also include a number of real–time examples from our own research. Forward and inverse kinematics of 3 DOF robot have been done then experiments on image processing, object shape recognition and pose estimation as well as target-block or object in Cartesian system and visual control of robot manipulator have been prescribed. Experimental results obtained from real-time system implementation of visual servo control and tests of 3DOF robot in lab.

Keywords: Position-based Visual servoing, Cross-layer, Forward and inverse kinematics, manipulator, Cartesian space

CHAPTER 1

1. INTRODUCTION

The domain of service and field robotics is developing rapidly with the emergence of new technologies and new needs. Figure 1 shows two examples of recently created robots that illustrate this development. This domain includes robots that operate in unstructured environments with little or even no prior information. In contrast to industrial robotics with defined constraints, tasks are variable and have to be performed autonomously.

Figure 1: Two recently created robots on the left is Jaco

Obviously, the control of a robot in such an unstructured environment has to rely on sense and perception. There are different sensor types such as force/tactile, inertial, range and visual sensors. This facilitates a large number of approaches and techniques to plan and control the movement of a robot. Some techniques already work reliably for specific tasks and are used in consumer products. One technique for more comprehensive areas of operation is known under the term visual servoing. The approach of visual servoing is to process sensor data of optical sensors such as cameras. By doing so, geometrical and qualitative information is obtained without physical interaction. This information is then used to plan and control the movement and interaction. As an example, consider a service robot that uses image data to be able to manipulate objects in its environment.

Visual servo control of a robotic manipulator has some step. Our working structure is described below by block diagram:

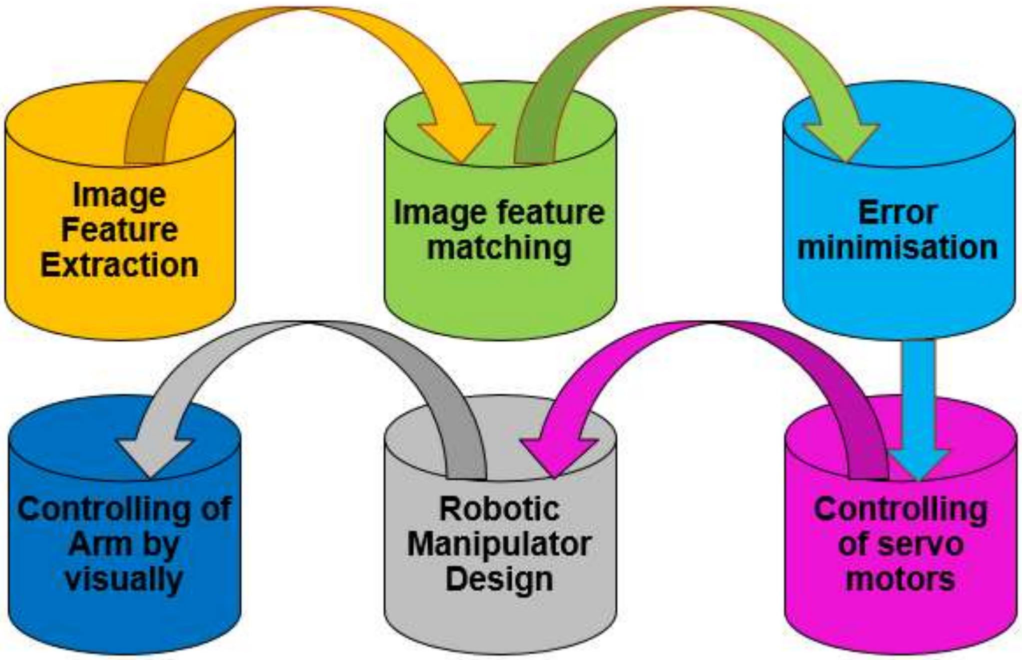

Figure 2: Working structure of Visual servo control of two-link and three DOF manipulator

The classification of visual servo control approaches depends on the design of the control method. Two different control schemes used:

1) Direct visual servoing system

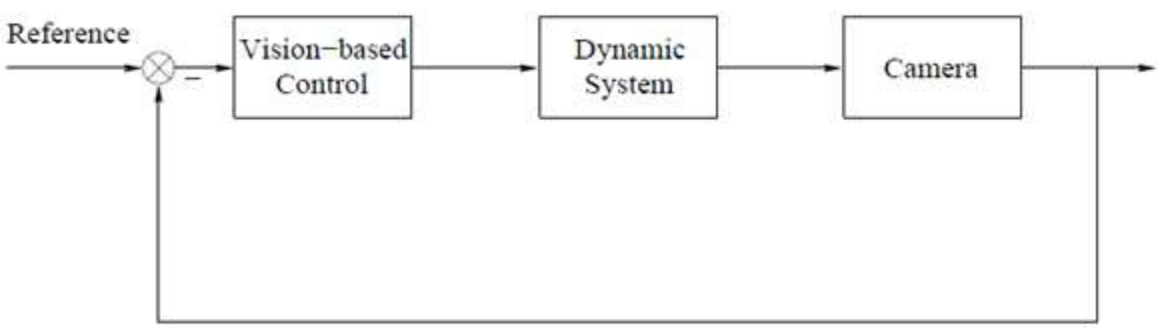

Figure 3: Direct visual servoing system

2) Indirect visual servoing system

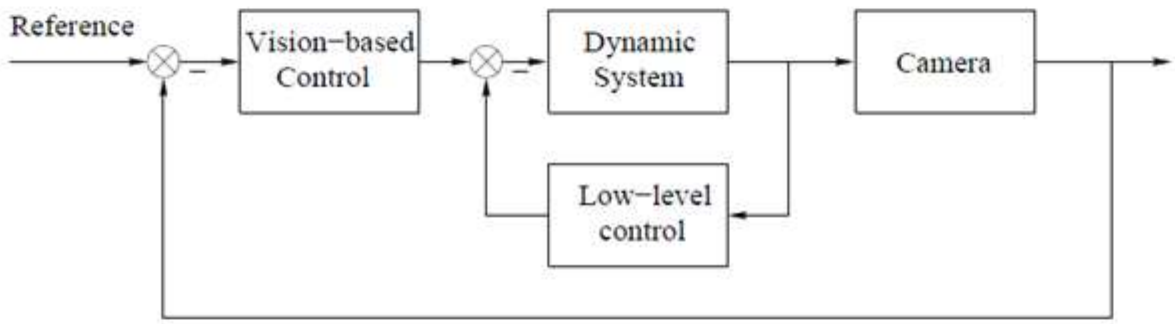

Figure 4: Indirect visual servoing system

Then kinematics equations of the robot are derived. After discussing simulation software of 3-DOF robot manipulator, we simulated control of robot and finally the results of tests MATLAB are analyzed.

1.1. Objective

The primary objectives of project are:

• To reduce the limitation of sensor based automation technology.

• To identify special feature like circle, point and region etc.

• To evaluation and testing of implementation of position based visual servo control

• To iimplementation of one specific flexible manipulator (grasping a object block)

• To investigate various object recognition and pose estimation algorithms and select those most suited to real-time control applications with human following in mind;

1.2 Motivation

The general motivation for field and service robotics originates from multiple fields. For example, these are underwater and aerial robotics, medical and domestic applications and robotics in hazardous environments. Figure 5 shows several robots from different fields. In general, the most important task in robotics is the manipulation (e.g. grasping, lifting, opening etc.) of an object. In order to manipulate an object, it is necessary to interact with the environment and to establish physical contact with the object. A safe and reliable interaction necessitates extensive gathering of information about the environment.

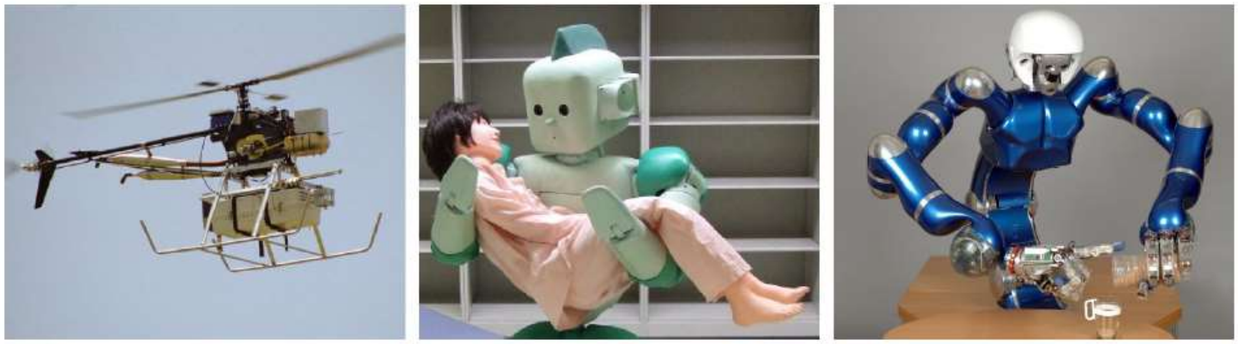

Figure 5: Some examples for robots that operate autonomously.
From left to right: Autonomous aerial robot, Health care robot, Domestic services robot

One way to collect this information about the environment of a robot is the use of computer vision. Camera images are processed and information that is needed to control the robot is extracted. This idea is motivated by the fact that humans and animals use primarily their visual perception to be able to interact with the environment. Many different approaches, adaptations and improvements for vision based control have been presented.

1.3 Thesis Organization

Chapter 2 gives basic introduction Background of real-time visual servo control of robot.

Chapter 3 provides method and technique of visual servo control of manipulator.

Chapter 4 provides the details of how to design of a flexible manipulator.

Chapter 5 provides the experimental result of project.

CHAPTER 2

2. BACKGROUND

A mobile robot has the ability to track a path and follow a rotating target, which required a lot of application. It is particularly occurs when the combination of multi-robot system required. Industrial robot system requires individual systems that are aware position and nature of surrounding agents.

The leader-follower controlling task required a mobile robot which followed by a target, maintain a specific range and relative position. Such type of task is particularly useful for robot which is traveling in vehicle groups for protection, where the head vehicle is the remote control and follows a cascade object, allowing the transport or vehicles by dangerous areas, without the requirement to human life. Leader-follower is also controlling by presumed to be high use in an advance transportation system.

The controlling of mobile robot systems using vision features in the feedback loop falls into the well-studied field of visual servo control. We are using two types of strategies: image-based visual servoing (IBVS) and position-based visual servoing (PBVS). IBVS refers to the control of a robot system in which calculations performed in the image plane system, by designing the of image point coordinate. PBVS refers to control strategies in terms of the visual system’s position relative to some reference coordinates.

Different types of visual servo system or camera placement position are used in combination with these visual servo control strategies. These control strategies include fixed location vision systems and eye-out-hand configurations. The camera Arm configuration defines to a vision servo system fixed to the controlled system, where camera rotation is constrained to movements made by the controlled system.

In the beginning, the robot is in an initial position and observes the manipulable objects. The end-effector (in this case the robot hand) then moves towards the object. This is done by using the image information that is acquired by the camera. When the final position is reached, the object can be manipulated.

The input of the created algorithm is the manipulation description and the image coordinates of an object. The manipulation description determines how the selected object is to be manipulated. This comprises the kind of manipulation (grasping, pushing, inserting) and the relative position and orientation (pose) of the end-effector with regards to the object. Additionally, the movement trajectory of the robot arm depends on the kind of manipulation. For instance if an object is to be pushed side wards, the end-effector has to approach the object at the same height. In such a scenario the orientation of the end-effector only plays a minor role. Conversely, if an object is to be grasped from above, the end-effector has to approach the object.

CHAPTER 3

3. METHODS AND TECHNIQUES

This chapter describes the important methods and techniques that were used for the implementation of project. These methods are all well-established. Therefore the overview in this chapter contains only the parts concerning this thesis.

3.1 Related Work

This section gives an overview of recent research results in the domain of visual servoing. The term visual servoing has been introduced in 1979 by Hill and Park. Since then the rapid technological development of cameras, computers and robots has opened up possibilities for improvements as well as new approaches and ideas. A recent comprehensive overview of all techniques that include visual systems in robotics is given by Kragic and Vincze. Besides the general overview they also provide introductions to specific fields, such as visual servoing. Furthermore, they cluster the existing branches into already working techniques and still open challenges. Another recent survey about the domain of visual servoing is presented by Kragic and Christensen. In this survey they summarize and classify about 100 different approaches according to the number of controlled degrees of freedom, the type of control model and the camera configuration. Hutchinson, Hager and Corke as well as Hutchinson and Chaumette, provide tutorials as an introduction to this field. The latter is also part of the most recent robotics compendium. This thesis is primarily based on these tutorials, but uses also ideas and techniques of other approaches. Besides the scientific articles, multiple software solutions and frameworks for visual servoing exist.

3.2 Robotics

Robotics is a highly multidisciplinary field of research. Given this fact, it is impossible to illustrate all the different branches in our thesis. As a result, only the most important techniques are presented with regards to the necessary adjustments.

3.2.1 Control System

A control system enables the connection between the sensory and the actuation system. Therefore it retrieves feedback data from the sensory system and adjusts the actions that are executed in an intelligent way. Joint space control and operational space control are the two possibilities for this. Figure 2.1 shows a control scheme for operational space control, figure 2.2 the equivalent scheme for joint space control.

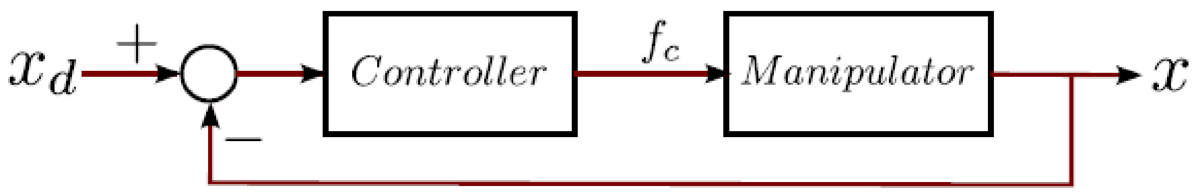

Figure 6: Operational space control scheme

Operational space control uses directly a desired position $x_d$and calculates the command forces f_c.

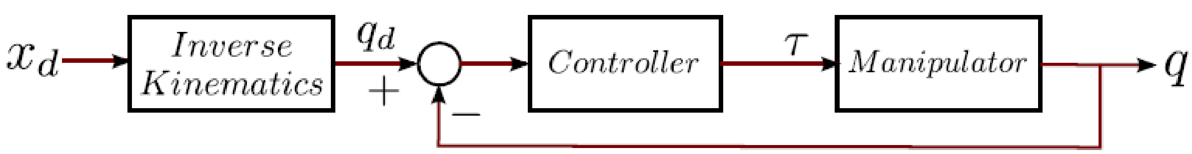

Figure 7: Joint space control scheme

Joint space control transfers the desired position to joint values q_d and calculates the command torques.

In joint space control, the control loop minimizes the task error in the joint space. Inverse kinematics is used to transfer the desired Cartesian position x_d into the vector q_d of joint coordinates. Typically, intermediate positions are calculated and the trajectory between these positions is interpolated.

On the contrary, the control loop of operational space control minimizes the task error in operational space. This is based on the dynamics of the robot expressed in operational space. A Jacobian matrix J(q) transforms the joint velocity vector $\dot{q}$ to the end-effector velocity vector $\dot{x}$.

$x = \dot{j}(q)\dot{q}$ or $q = j(\dot{q})\dot{x}$ q …………………(1)

Operational space control is typically the control mode for visual servoing.

Unfortunately, it turned out that the chosen robot platform did not support this mode of control. Consequently, joint space control was used in this thesis which leads to several shortcomings (see section 5.2 for a discussion of the problems). Nevertheless, the presented work can easily be used with operational space control if the robot supports this.

3.2.2 Visual Servoing

Visual servoing is the process of using data from vision sensors in the control loop of robots. It is similar to active computer vision with regards to the gathering of information (given the case that the camera is mounted on the robot). These forms are image-based, position-based and hybrid visual servoing. The categorization is based upon the formulation of the error. Image-based approaches try to minimize the error (distance between the desired value and current value) in the image space, whereas position-based approaches minimize the error in 3D space. Hybrid approaches deal with error functions in more than one space. Figure 2.3 shows the differences between the three control modes.

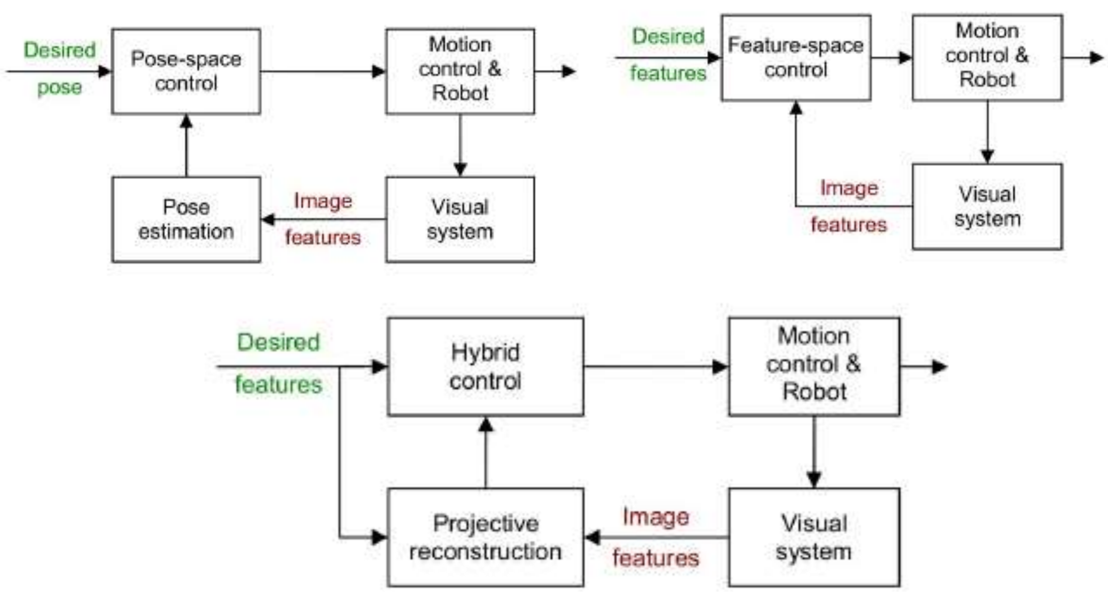

Figure 8: Classification of visual servoing based on the formulation of the control error
Top left: Position-based control. Top right: Image-based control. Bottom: Hybrid control.

Besides, there is a second criteria that subdivides visual servoing according to the camera configuration. The most popular groups are eye-in-hand and eye-to-hand mounting. In the former group the camera is fixed to the end-effector of the robot, in the latter the camera is stationary in the world and observes the end-effector.

3.2.3 Coordinate Transformations

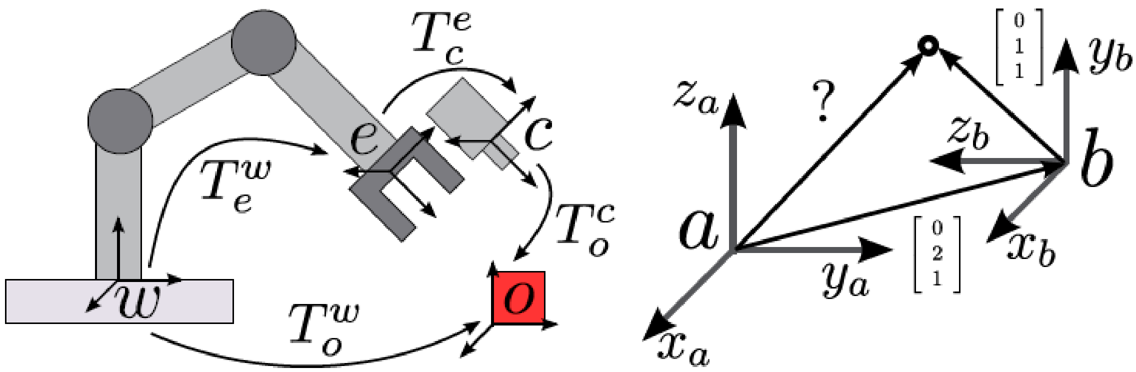

Figure 9: The concept of coordinate transformations is illustrated in this image

The left image shows a robot with several relevant coordinate frames and the transformations between them. These are the world coordinate system w, the end-effector coordinate system e, the camera frame c and the coordinate system attached to the object o and the corresponding transformations Tab. The right image shows two coordinate systems a and b and is used as an example for a transformation.

Transformations describe the relation between coordinate systems and are used to transform coordinates from one system to another. Usually, they are expressed in homogeneous coordinates.

This transformation matrix is composed of a 3×3 rotation matrix and a translation vector from a to b. The columns of the rotation matrix are the three unit vectors of frame b expressed in frame a. The last row is the homogeneous augmentation. In the example, the coordinates of the point with regards to the system b are given as p_b. The transformation then can be used to transform the point to the coordinate system a. This is done with a simple multiplication of the transformation matrix with the point in homogeneous coordinates.

$$p_a = T_{ab\_}p_b$$

The concept of these transformations simplifies the change of coordinate systems to a large degree. More information on relevant mathematics can be found in.

3.3 Mathematics Derivation of System

Camera – 1:

Let's assume point is input $P_1 \equiv [X_1, Y_1]$ and $P_2 \equiv [X_2, Y_2]$

So, distance between points is: R = $\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$

From Rectangle Triangle P_1P_2P

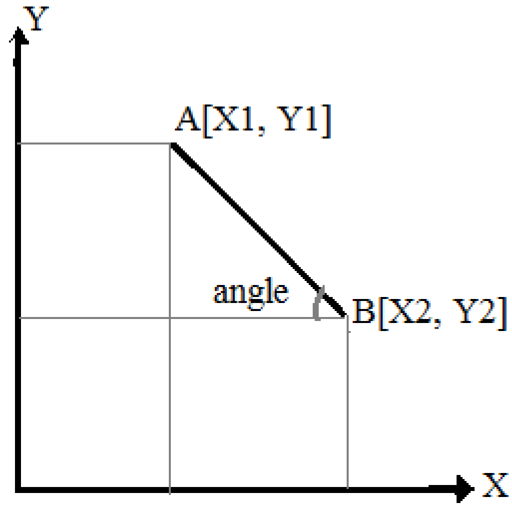

Figure 10: Coordinate system of input point

$$RCos\emptyset_1 = X_2 - X_1 \quad \ldots\ldots (1)$$

$$Cos\emptyset_1 = \frac{X_2 - X_1}{R} \quad \ldots\ldots\ldots\ldots (2)$$

$$\emptyset_1 = \cos^{-1}\left(\frac{X_2 - X_1}{R}\right) \quad \ldots\ldots\ldots\ldots (3)$$

We have to follow $\emptyset_1$ *to* $\emptyset_2$

For Servo Motor:

PWM Value	0	0.4	0.5	1
Angle(Degree)	0	72	90	180

Table – 1: Servo motor pulse value and related angle value

Proportional Controller:

V (Ø) = KØ ……………. (4)

K= constant value

V= Pulse Value

$\emptyset = Angle\ of\ Rotation$

So Value of $K = \frac{V}{\emptyset}$

$$K = \frac{V}{\emptyset} = \frac{0.4}{72} = \frac{0.5}{90} = \frac{1}{180}$$

Value of K (in Radian) = $\frac{1}{\pi}$

So Value of Pulse:

V (∅) = K∅

$$V = \frac{1}{\pi}\left(\cos^{-1}\left(\frac{X_2 - X_1}{R}\right)\right) \quad \ldots\ldots. (5)$$

Camera – 2: X- Z Plane

Let's assume point is input $A_1 \equiv [X_1, Z_1]$ $A_2 \equiv [X_2, Z_2]$ and $A_1 \equiv [X_3, Z_3]$

We Know That

$P_1P_2 = L_1$ ……….. (1)

$P_2P_3 = L_2$ ……….. (2)

$P_2P_3 = L_3$ ……….. (3)

$P_2P_4 = L_2 Cos\emptyset_1$ ……….. (4)

$P_1P_4 = L_1 + L_2 Cos\emptyset_1$ …………. (5)

$P_1P_4 = L_3 Cos\emptyset_2$ ………………..(6)

$L_1 + L_2 Cos\emptyset_1 = L_3 Cos\emptyset_2$………………..(7)

$$\frac{a}{\sin X} = \frac{b}{\sin Y} = \frac{c}{\sin Z}$$

$$\frac{L_1}{\sin(\emptyset_1 - \emptyset_2)} = \frac{L_2}{\sin \emptyset_2} = \frac{L_3}{\sin(\pi - \emptyset_2)} \ldots\ldots\ldots\ldots. (8)$$

$$\frac{L_1}{\sin(\emptyset_1 - \emptyset_2)} = \frac{L_2}{\sin \emptyset_2} = \frac{L_3}{\sin(\emptyset_1)} \ldots\ldots\ldots\ldots. (7)$$

$$\frac{L_2}{\sin \emptyset_2} = \frac{L_3}{\sin(\emptyset_1)} \quad \Rightarrow \quad sin\emptyset_1 = \left(\frac{L_3 \sin(\emptyset_1)}{L_2}\right) \ldots\ldots\ldots\ldots. (9)$$

Solving following Equation:

$L_2\ sin\emptyset_1 = L_3 \sin(\emptyset_1)$

$L_1 + L_2 Cos\emptyset_1 = L_3 Cos\emptyset_2$

$L_1 = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$

$L_2 = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$

$L_3 = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$

Final Value of $\emptyset_1$ & $\emptyset_2$

$\emptyset_1 = \frac{\pi}{2} - tan^{-1}\left(\frac{Y_3 - Y_2}{X_3 - X_2}\right)$……………………(10)

$\emptyset_2 = \frac{\pi}{2} - tan^{-1}\left(\frac{Y_3 - Y_1}{X_3 - X_1}\right)$……………….......(11)

Final Value of V_1 & V_2

$V_1 = \frac{1}{\pi} - \left(\frac{\pi}{2} - tan^{-1}\left(\frac{Y_3 - Y_2}{X_3 - X_2}\right)\right)$ ……………….(12)

$V_2 = \frac{1}{\pi} - \left(\frac{\pi}{2} - tan^{-1}\left(\frac{Y_3 - Y_1}{X_3 - X_1}\right)\right)$ ……………………..(13)

Value of pulse (V1 & V2) is depending on position of coordinate of image frame. There is no effect of frame transfer on output but if frame will rotate than value of pulse will change.

CHAPTER 4

4. ROBOTIC MANIPULATOR DESIGN

The manipulator is the commonly device used in automation industry. The mathematically equation of manipulator is used for design a robot manipulator perfectly. All term related to manipulator is defined below:

4.1 Degrees of Freedom (DOF)

The degrees of freedom are commonly used term related to a manipulator. Degree of freedom is make connection of all links, at a place where manipulator can move. We can identify the number of DOF by the number of motors or actuators in the robot manipulator.

4.2 Denavit-Hartenberg (DH) Convention

The Denavit-Hartenberg (DH) Convention is drawing of free body diagram of manipulator. Manipulator has two type of motion like: rotation and translation. Manipulator has 3 axes to rotate in z-plan. Figure 1 shows some of robot manipulators which is used to draw FBD of manipulator. We don't count gripper as a DOF.

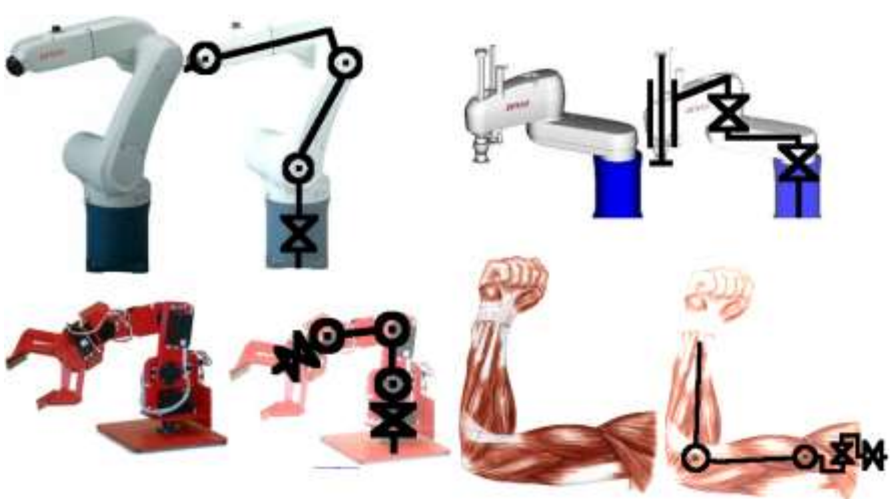

Figure 11: DOF, 4 DOF and 5 DOF Robot manipulator

We can take an example of human-shoulder. Human shoulder has three Continuous DOF.

4.3 Robot Workspace

The robot workspace (sometimes known as reachable space) provides the space that ends effector can move. The workspace is completely depending on the DOF and angle. The workspace is also dependent on the manipulator configuration. We choose 3 DOF configurations for simplicity.

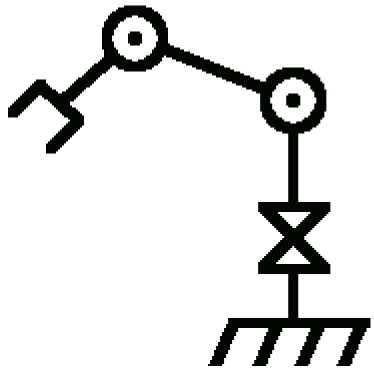

Figure 12: Free Body diagram of 3 DOF manipulator

Let's consider that all DOF can move a max of 180 angles, because the servo motors can't go to 180 degree angle. We can find the workspace; track all points that the gripper can move as in the figure below.

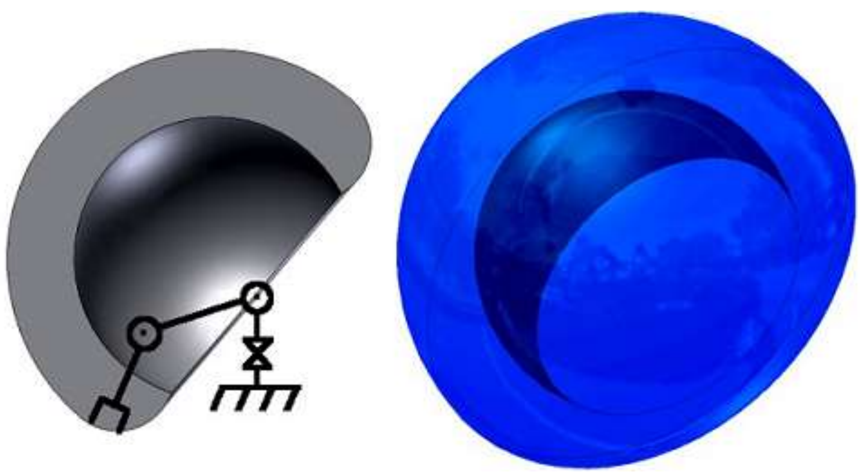

Figure 13: Workspace of 3 DOF ARM Manipulator

Now rotating that by the base joints another 180 degrees to get 3D, we uses servos motor all joints are limited to a max of 180 degrees. This creates a workspace of a shelled semi-sphere.

4.4 Mobile Manipulators

A moving robot manipulator is a sub-class of robotic arms. They work just like other robotic manipulator, but the DOF of the robot is added to the DOF of the arm 2 DOF with a 5 DOF that would give the robot arm a total sum of 7 DOF.

Figure 14: Mobile Robot contains 3 DOF ARM

4.5 Calculations of Joints Force

The first step is to draw FBD, with the robot arm rotate out to its maximum length.

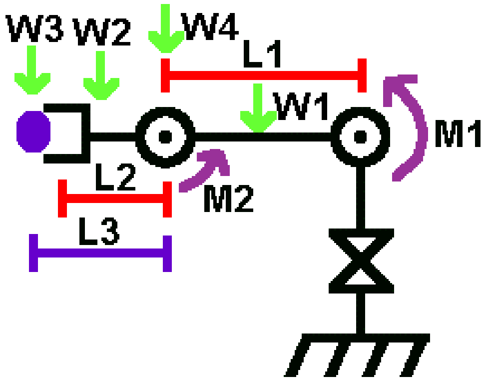

Figure 15: FBD of 3DOF Manipulator

Choose these parameters:

- Weight of each linkage
- Weight of each joint
- Weight of object to lift
- Length of each linkage

Torque Joint 1:

$$M_1 = \frac{L_1}{2} \times W_1 + L_1 \times W_4 + \left(L_1 + \frac{L_2}{2}\right) \times W_2 + (L_1 + L_3) \times W_3$$

Torque Joint 2:

$$M_2 = \frac{L_2}{2} \times W_2 + L_3 \times W_3$$

4.6 Motion Planning

The end effector can traverse the space, except now it must also make sure the other joints and links do not collide with anything too.

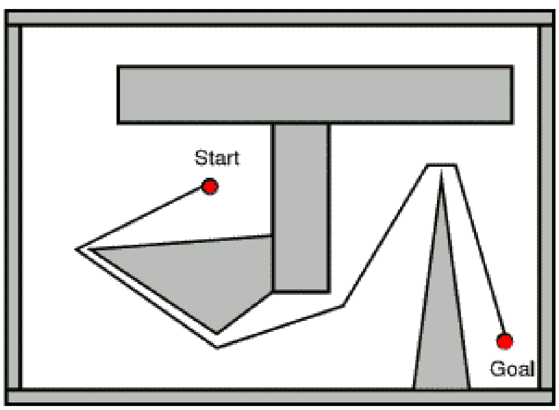

Figure 16: Path Detection of manipulator

CHAPTER 5

5. EXPERIMENTAL ANALYSIS

This thesis shows work completed on the design of control and vision components for use in a vision-based human-following robot. To test the implementation the robot performed one specific manipulation several times. The type of manipulation was the grasping of an object from above. Different objects without special visual properties (color, markers, etc.) were used. The movement trajectory was recorded in the form of absolute Cartesian positions of the end-effector. Furthermore, the estimation of the object position and the feature coordinates were recorded.

The experiments are performed to analysis various aspects of the implementation. First, object feature is detected and all calculation done. Second, Design of robotics manipulator is done in solid works software and in real time system. The third interesting aspect is the refinement of the object position estimation. And last, visual aspects such as the use of plain objects, the tracking error and triangulation results are tested and analyzed. A conclusion that considers all different results is presented.

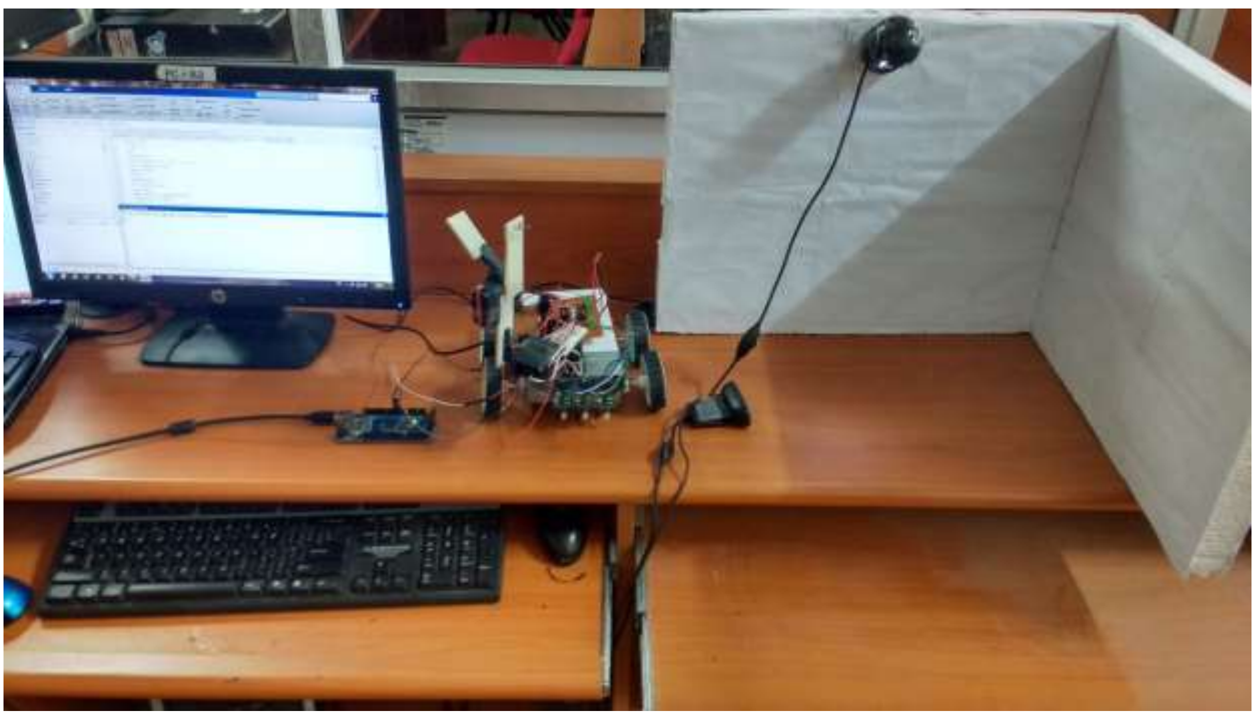

Figure 17: Real time system of position visual servo control

5.1 Object Detection

We described an object detection system based on marker detection (like circle, line etc). The resulting system is both efficient and accurate and depends on position of object in 2D coordinate system. Our models are already capable of representing highly variable object classes. Here is some object detected figure is shown:

Figure 18: Object Detection by system

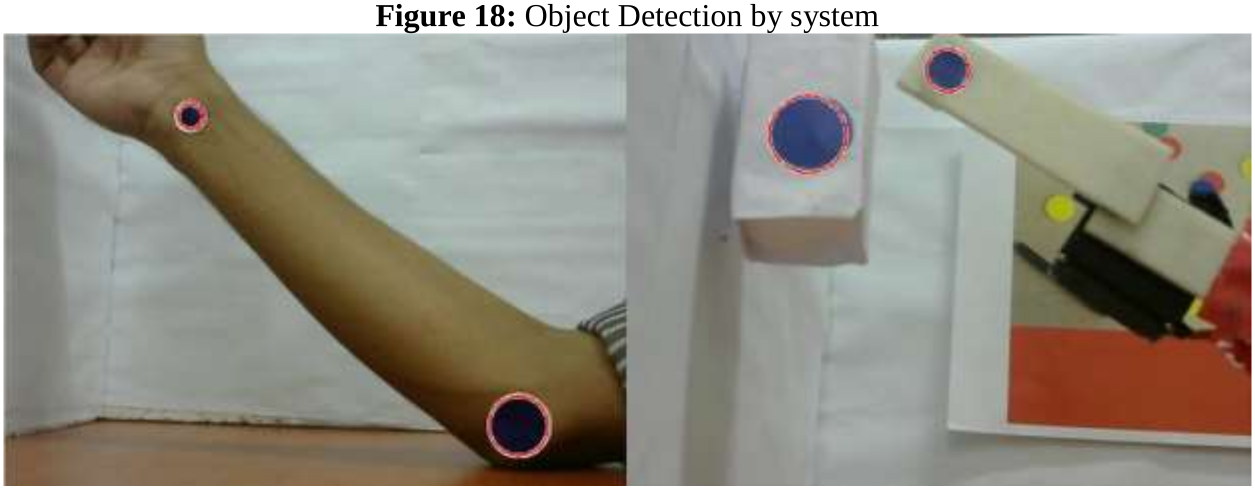

Figure 18: Object detection on other platform or different input

5.2 Two - Link & Three DOF Manipulator Design

Robotics manipulator arms Design is world-class products in industrial automation, Automation-operation and materials handling that much productivity and reduce operating costs with human effort. These products' dexterous and rugged designs allowed to carry exceptional heavy loads, and are perfect for inaccessible tight and obstacle much spaces where no other product can face these challenges.

We will design a manipulator to perform the mechanical design of a 3-DOF lightweight for assembling bar structures using solid works software. The architecture and mathematical derivation show in manipulator design chapter. The manipulator design consists of a base attached to mobile robot, a robotic arm that supports 3-DOF, and a gripper-design end effector specifically developed for grasping blocks as a result of this study.

Figure 19: Solid works design of manipulator from all view

Practical Design of robot can't be same as software design, because of robot is not perfectly designed in 3D printing machine. We kept one hand of griper is content and one is moving with servo motor.

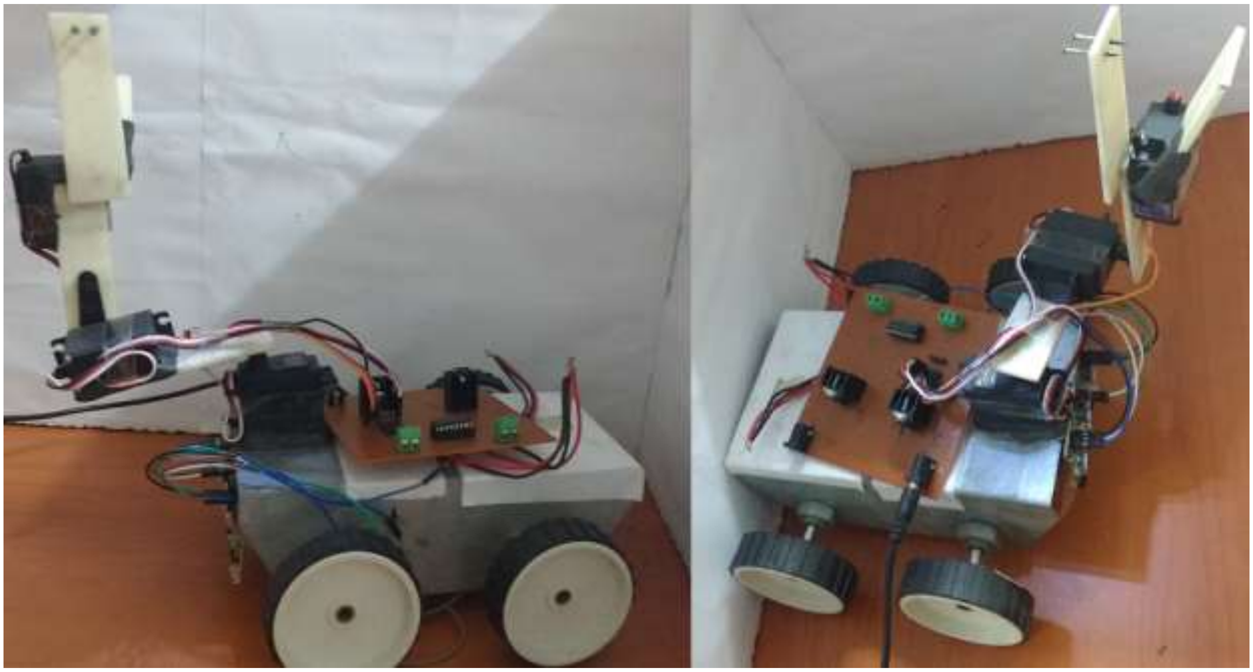

Figure 20: Practical design of mobile robot manipulator.

5.3 Algorithm Of Visual servo control of Arm Manipulator

1. Initialize both the camera
2. Declare the object for camera
3. Initialize Arduino board for matlab
4. Declare the position of signal pin on Arduino board and define object for Arduino board
5. Detect the object (marker) in real time system
6. Find coordinate of all center point of marker
7. Calculate the angle and all distances
8. Calculated required formula value for control signal
9. Find the error of desired and input value
10. Go to Step 6
11. Exit the program up to error value become zero

5.4 Error Calculation

The data of the experiment or trial is contained in the corresponding column. The row Object names the object that was used for this specific trial. The 2D error represents the angle (in degree) from the selection center before the movement to the selection center after the movement. The error is the measured angle (in degree) between the optimal grasping positions (determined by hand) and the reached position after the movement. The estimation change is the distance between the initial estimation and the final estimation of the position (in degree). It thus represents the total change of the estimation.

Actual Angle(degree)	Angle calculated after feature extraction(Degree)	Rotation Angle in Servo - 1	Rotation Angle in Servo - 2	Rotation Angle in Servo - 3
90	84.4	82.1	81.2	0
75	69.1	68.3	69.8	0
60	56.5	55.2	55.1	55
45	42.5	41.9	42.6	42.2
30	28.9	28.3	27.6	27.3
20	19	18.7	18.2	18
10	9.8	9.5	9.8	9.8

Table 1: Error Estimation Table with Robotic Arm & Input angle

These results may not be completely representative. Table 2 contain the only experiment data.

The total success rate of more than 70% suggests that the presented technique principally works. A further interpretation follows after the remarks for individual trials:

- Trial 1: The tracked features were partially out of the field of view at the end of the movement. Therefore, the selection center moved and the 2D tracking error was relatively large.
- Trial 2: The 2D position error was large due to a wrong initial estimation. The estimation error could not be calculated for the same reason.

- Trial 3/8: Due to a bad solution of the inverse kinematics all tracked features left the field of view. As a result, the complete trial was stopped and no data could be acquired.
- Trial 9/12: The object (the hand) could not be grasped because of its orientation.
- Trial 13/17: The large 2D error was mainly in the vertical direction.

5.5 Trajectory Analysis

We took some sample coordinate to track hand moment by manipulator. We took two type of Trajectory for reference: 1) Circle Trajectory 2) line Trajectory.

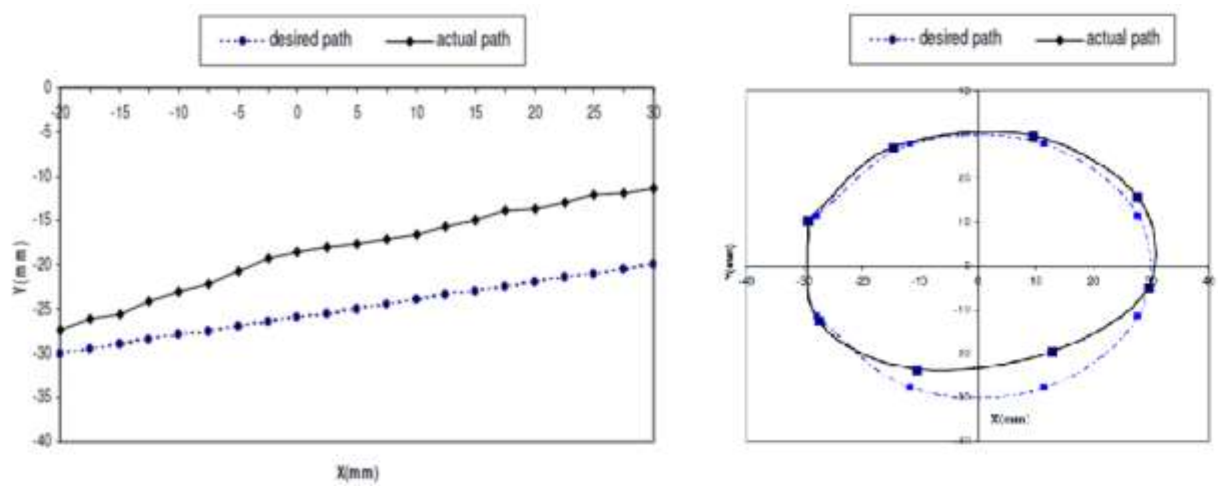

Figure 21: Circular and line path trajectory by input image cordinate and arm point coordinate

CONCLUSION

Visual Servo control technique is a very reliable technique for controlling autonomous real-time dynamic systems. A lot of applications, from object block grasping by robot manipulator on mobile robot platform navigation are possible. It has been represented how to use a position based vision based servo control system and test the 3 DOF robots manipulator. In our system, there is no requirement to know the first coordinates of robot manipulator or object block target to calculation the needed movement. In the starting, visual servo control techniques are using for a 2D model of the positioning work were performed by position-based visual servoing. Position-based visual servo control techniques allowed positioning of the robot manipulator with respect to an object. We took real time images will help us to calculate the distance and angle of the object to the end effector point. This is one more of the advantages of this visual servo control system. The position of the objects is calculated during the visual servo control loop. This calculation depends on the known camera position and the tracking feature of image.

By applying visual control system, the angle and distance parameters of the input feature of images are found. Arduino board processed data with speed of 9600 bps. The test errors in angle have been calculated and analyzed and also compute in MATLAB the path trajectory parameters of 3 DOF robots.

The main motive of this work is the described the visual servo control loop. Purely visual based human arm following systems typically lack the performance of those using multiple camera and fused layers of detectors to increase available target object information. For the purposes of this work, only the visual component of multi-layered trackers, with the option to expand left as future work.

FUTURE WORK

The future work is concerned with extending the with higher DOF. Investigate feedforward techniques to improve the control. Future work for that is:

- Extending the approach to more general visual servoing system with 6 DOF.
- Sensor can use in addition to the vision sensors to detect physical parameter, which is required for manipulation tasks.
- Minimize error function as much as possible.
- Increase number of camera for good input.
- Control the speed of servo motor by vision system.

A velocity vector can be calculated and used for the movement. Further tasks could include the extension of the tracking module. In the presented implementation, the object is only represented by a set of features in image space and one point in 3D space. During the movement, the position in 3D space is estimated but further information about the structure of the object is discarded. One could also use object recognition for the unsupervised selection of objects. Additionally, there are more sophisticated ways to generate movement trajectories. A force sensor can use in addition to the vision sensors to detect physical contact, which is required for manipulation tasks.

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